How common is imaging for low back pain in primary and emergency care? Systematic review and meta-analysis of over 4 million imaging requests across 21 years.

Authors' names
Aron Downie, Mark J Hancock, Hazel Jenkins, Rachelle Buchbinder, Ian Harris, Martin Underwood, Stacy Goergen, Chris G Maher

Aron Downie, **corresponding author**
PhD (Candidate)
1. Institute for Musculoskeletal Health, Sydney School of Public Health, Faculty of Medicine and Health, The University of Sydney. PO Box M179, Missenden Road NSW 2050, Australia.
2. Faculty of Science and Engineering, Macquarie University, Australia.
aron.downie@sydney.edu.au

Mark J Hancock
Associate Professor, Faculty of Medicine and Health Sciences, Macquarie University, Australia.
mark.hancock@mq.edu.au

Hazel Jenkins
Lecturer, Faculty of Science and Engineering, Macquarie University, Australia.
hazel.jenkins@mq.edu.au

Rachelle Buchbinder
Professor, Department of Epidemiology and Preventive Medicine, School of Public Health & Preventive Medicine, Monash University and Monash Department of Clinical Epidemiology Cabrini Institute, Australia.
rachelle.buchbinder@monash.edu

Ian Harris
Professor, South Western Sydney Clinical School, University of NSW, Australia.
ianharris@unsw.edu.au

Martin Underwood
Professor, Warwick Clinical Trials Unit, The University of Warwick, United Kingdom.
M.Underwood@warwick.ac.uk

Stacy Goergen
Adjunct Clinical Professor, School of Clinical Sciences, Monash University, Australia.
Stacy.Goergen@monashhealth.org

Chris G Maher
Professor, Institute for Musculoskeletal Health, Sydney School of Public Health, Faculty of Medicine and Health, The University of Sydney, Australia
christopher.maher@sydney.edu.au

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ABSTRACT

Objectives: To (i) estimate the proportion of patients seeking care for low back pain (LBP) who are imaged, and (ii) explore trends in the proportion of patients who received diagnostic imaging over time. We also examined the effect of study-level factors on estimates of imaging proportion.

Data sources: Electronic searches of MEDLINE, EMBASE, and CINAHL databases from January 1995 to December 2017.

Eligibility criteria for selecting studies: Observational designs and controlled trials that reported imaging for patients presenting to primary care or emergency care for LBP. We assessed study quality and calculated pooled proportions by care setting and imaging type, with strength of evidence assessed using the GRADE system.

Results: 45 studies were included. They represented 19,451,749 consultations for low back pain that had resulted in 4,343,919 imaging requests/events over 21 years. Primary care: moderate quality evidence that simple imaging proportion was 16.3% (95%CI 12.6 to 21.1) and complex imaging was 9.2% (95%CI 6.2 to 13.5). For any imaging the pooled proportion was 24.8% (95%CI 19.3 to 31.1). Emergency care: moderate quality evidence that simple imaging proportion was 26.1% (95%CI 18.2 to 35.8) and high quality evidence that complex imaging proportion was 8.2% (95%CI 4.4 to 15.6). For any imaging the pooled proportion was 35.6 % (95%CI 29.8 to 41.8). Complex imaging increased from 7.4% (95%CI 5.7 to 9.6) for imaging requested in 1995, to 11.4% (95%CI 9.6 to 13.5) in 2015 (relative increase of 53.5%). Between-study variability in imaging proportions was only partially explained by study-level characteristics; there were insufficient data to comment on some pre-specified study-level factors.

Summary/conclusion: One in 4 patients who presented to primary care with low back pain received imaging as did one in 3 who presented to the Emergency department. The rate of

complex imaging appears to have increased over 21 years despite guideline advice and education campaigns.

Introduction

Low back pain (LBP) is a major contributor to disease burden worldwide;[1] with higher prevalence in athletes than in the general population.[2] The majority of LBP has no known patho-anatomical cause; presentations due to a specific disease process (eg, infection, malignancy) are uncommon in primary care.[3] Diagnostic imaging is only recommended for low back pain without radicular pain when there is suspicion of a specific disease process (eg, malignancy, fracture, infection, or spondyloarthropathies) that would be managed differently to non-specific LBP.[4-6]

Overuse of imaging for LBP has been reported for many decades with studies reporting that 20% of patients presenting with LBP received imaging in the UK,[7 8] and 25% in Australia[9] and USA.[10] However, the veracity of these estimates is unclear as there has not been a systematic review of studies evaluating the frequency of imaging in patients presenting for care with LBP.

In this systematic review our aims were to (i) estimate the proportion of patients seeking care for LBP who are imaged currently; (ii) explore trends in the proportion of patients receiving diagnostic imaging over time. We also examined the effect of study-level factors on estimates of the imaging proportion. We hypothesised that the imaging proportion should have decreased over time as a result of clinical practice and therapeutic guidelines to limit imaging and more recently through campaigns such as Choosing Wisely (launched in 2012) warning about overuse of imaging for LBP.[11-15]

Methods

The study protocol was pre-specified, and the review conducted in accordance with PRISMA and MOOSE guidelines.[16] [17] The study protocol was registered with PROSPERO (http://www.crd.york.ac.uk/PROSPERO); registration CRD42016041987.

Searches

We searched MEDLINE, EMBASE and CINAHL for articles published between 1st January 1995 and 9th December 2017 in any language. The rationale for searching from 1995 was that the first evidence-based LBP guideline to provide advice for use of imaging was released in 1994.[18] Search terms relating to primary or emergency care, imaging type, and LBP were used (**Appendix 1**: MEDLINE search string). We supplemented electronic searches with hand searches of reference lists from eligible studies and contacted experts in the field of imaging and management of LBP. Two authors (AD and HJ) independently performed title and abstract screening with full-text articles assessed for study eligibility. Any disagreements were resolved by consensus.

Study selection

Eligible study designs were controlled trials, and observational designs (cohort, case-control, cross-sectional, and interrupted time series). Studies needed to report on imaging requested or performed for patients presenting to primary or emergency care for LBP. We defined *primary care* as first contact care with a provider who could refer for imaging, including medical practitioners (eg, general practitioners), and allied health practitioners (eg, physiotherapists chiropractors, osteopaths). We defined *emergency care* as first contact care in the hospital emergency department setting. Studies were ineligible if not written in English and translation to English was not feasible, if all participants were imaged, or if greater than 25% of the participant sampling frame was prior to 1995.[18]

Data extraction and risk of bias assessments

After all eligible studies were retrieved, two of four authors (AD, MH, HJ or CM) independently extracted data and assessed risk of bias with disagreements resolved by

consensus, or a third rater, if required. Data from each study were extracted using a pre-piloted form. Where available, we extracted data on: year of publication, study design, country, clinical setting, imaging modality, study sampling frame, imaging observation window (period of time between presenting to the clinician and the last time point at which data on imaging request/event was collected), participant characteristics, imaging proportion, and study sample size. Authors were contacted to request additional data where required. We extracted imaging proportion based on the entire study sample for observational studies. For controlled trials testing strategies to reduce imaging we extracted data from the control arm only.

Risk of bias was assessed using the tool developed by Hoy et al. for assessing risk of bias of prevalence studies (2012).[19] The tool comprises 10 items scored for risk of bias (low risk, high risk). Modification was made to two of the original 10 items to reflect the aims of this study. *Representative population* (item 1) was specified as a population seeking primary or emergency care for LBP, and *prevalence period* (item 9) was specified as the imaging observation window. We generated an overall summary risk of bias score (low, moderate, high risk) based on consideration of the 10 items.[19] Any disagreements were resolved by consensus or a third rater.

Data synthesis

We defined *simple imaging* as plain radiography or ultrasound (U/S); *complex imaging* as CT, MRI or nuclear bone scan; and *any imaging* as the aggregate of simple and complex imaging when a study reported both. We defined *current imaging* for studies with greater than 75% sampling frame from 2010 or later. We extracted data from the most recent study when multiple studies reported on the same source data. The imaging proportion was calculated by extracting imaging counts, either requested or performed as a result of seeking care (numerator), divided by the sample size (denominator). To represent each study sampling frame, a single time-point (*year*) was calculated using the midpoint of the date range. When the study sampling frame

was continuous, a single average imaging proportion was calculated. For discontinuous sampling frames (eg, 2002–03; 2011–12) average imaging proportions representing each period were calculated.

Data analysis

Current imaging proportion

To estimate the current imaging proportion we calculated pooled proportions, grouped by clinical setting (primary or emergency), then by imaging type (simple, complex, or any) using random-effects meta-analysis. The relative study weights assigned under a random-effects model are minimally influenced by extremes in study populations.[20] [21] Outlier studies (identified by visual inspection of the forest plot) were described and excluded from pooled analyses. Some clinical heterogeneity was expected due to variation in study population and clinical features.[22] Statistical heterogeneity was assessed, however, meta-analysis was not deemed inappropriate simply due to high I^2 values, as long as the individual study estimates fell in a reasonable range.[23] [24] Sensitivity analyses of pooled imaging proportions were performed based on summary risk of bias (high vs low or moderate risk). Each pooled proportion was graded for quality of evidence.

To assess quality of the evidence for pooled estimates of imaging proportion we applied GRADE criteria for observational studies.[25] [26] Two reviewers (AD, HJ) scored four factors for each pooled estimate. Quality of evidence began as high and was downgraded one level for each of limitations in study design (for instance, <50% of studies were observational – potential for selection bias), summary risk of bias (>50% of studies scored moderate or high), inconsistency of results (imaging proportion point estimates had an absolute range >25%) and imprecision (the confidence interval of the pooled estimate spanned >10% above or below the pooled estimate). Thresholds for downgrade were based on consensus.[26] Indirectness of

evidence was measured as part of the summary risk of bias. Any disagreement was resolved by consensus or a third rater.

Trends in frequency of diagnostic imaging

We explored trends in imaging over time for simple and complex imaging, using mixed-effects meta-regression with important pre-specified study-level factors considered as covariates.[27 28] We considered factors for regression if reported by greater than 85% of studies.[27] We performed a univariate analysis for each factor. We built two multivariate models (simple imaging, complex imaging) with study year selected and other factors added. Final selection of study-level factors was based on clinical rationale (not data driven), testing for collinearity (VIF <4)[29] and ensuring the model was not overfit based on the number of available studies. We identified, then considered excluding from regression, extreme outlier studies based on a plot of standardised shrunken residuals as recommended by Harbord and Higgins (2008).[30] Statistical analyses used STATA-IC v15 (StataCorp, USA) –metareg,[30] and Comprehensive Meta Analysis v3.3 (Biostat, USA).

Results

The electronic database search and citation tracking identified 5,011 potential studies of interest. After screening of titles and abstracts, we retrieved full text copies of 191 articles. Forty-five studies were included in the review (42 unique data sources). Key reasons for exclusion included: imaging proportion inestimable, inappropriate study design, and >25% of the participant sampling frame prior to 1995 (**Figure 1**).

Characteristics of included studies

The forty-five studies we identified represented 19,451,749 unique consultations to primary or emergency care which resulted in 4,343,919 imaging requests/events over a 21 year period (September 1994 – July 2015).[7-10 14 31-70] Study sample size ranged from 55[55] to 10,255,661

participants,[49] with government-supported studies the commonest. The majority of studies were from North America (Canada [2 studies], United States [29 studies]), followed by Oceania (Australia [5], New Zealand [1]), Europe (Germany [1], Italy [1], Poland [1], Spain [3]), and UK (England [2]). Two studies studied exclusively elderly participants.[10 60] The majority of studies were retrospective reviews of clinical records or insurer data. Most commonly reported modalities were radiography, CT and MRI. A small proportion of patients presenting with LBP received diagnostic ultrasound: Britt et al. (2014)[34] (0.4%, 2002-05; 0.6%, 2009-12) and Allen (2014)[31] (0.6%, 2001-09). However, neither study provided details about what structures were scanned. Ultrasound is not appropriate for identifying the usual or common serious causes of low back pain including fracture and cancer, but may be considered in patients with suspicion of abdominal aortic aneurysm[71] or renal colic.[72 73] Radionuclide bone scan was also reported by Britt et al. (2014)[34] (0.3%, 2002-05, 0.2%, 2009-12). Thirty-six of the 45 studies (80%) had an imaging observation window within 3 months. The imaging observation window ranged from same day (eg, imaging data from the emergency setting),[62] out to 1 year (eg, review of private health insurer data).[43] Study characteristics are provided in **Table 1**.

The majority of studies scored moderate or high for summary risk of bias (N=34, 76%). The most frequent reasons for high risk of bias were non-representative sample (eg, by excluding the elderly), broad case definition, or imaging observation window greater than 4 weeks (**Table 2**).

(i) Current imaging proportion (2010 or later)

Sixteen studies provided information on current imaging, of which 12 collected data from primary care,[14 34-36 43 44 50 53 55 61 67 68] and four from emergency care.[59 61 62 65] Two studies measured imaging in both settings, either reported separately,[61] or combined.[63]

Current imaging in primary care

The pooled estimate of current proportion for *simple imaging* in primary care (N=7; n=1,574,236) was 16.3% (95%CI 12.6 to 21.1), rated as GRADE: moderate quality evidence. We considered Carey et al. (2015)[35] (estimate: 56.9%, 95%CI 49.9 to 63.7; **Appendix 2**), an outlier so did not pool (the high estimate was potentially influenced by participant self-report). For *complex imaging* (N=8; n=2,323,559), the pooled proportion was 9.2% (95%CI 6.2 to 13.5), GRADE: moderate quality evidence. We excluded Carey et al. (2015)[35] from pooling as above (estimate: 80.1%, 95%CI 74.2 to 84.9). For *any imaging* (N=8; n=1,675,720), the pooled proportion was 24.8% (95%CI 19.3 to 31.1), GRADE: moderate quality evidence (**Figure 2**). Summary risk of bias (high vs low or moderate risk) did not significantly influence pooled proportions in primary care (P=0.21, 0.59, between group mixed-effects analyses for simple and complex imaging respectively) (**Appendix 3**).

Current imaging in emergency care

The pooled estimate of current proportion for *simple imaging* in emergency care (N=4; n=16,552) was 26.1% (95%CI 18.2 to 35.8), GRADE: moderate quality evidence. For *complex imaging* (N=4; n=16,552), the pooled proportion was 8.2% (95%CI 4.4 to 15.6), GRADE: high quality evidence. For *any imaging* (N=4; n=16,552) the pooled proportion was 35.6% (95%CI 29.8 to 41.8), GRADE: high quality evidence. (**Figure 2**).

(ii) Trends in frequency of diagnostic imaging over time

After removing duplicate data-sets 42 studies were available for meta-regression.[46 56 63] See **Appendix 2** for imaging proportion of all available studies. Of twelve pre-specified study-level factors, four were ineligible (reported by less than 85% of studies) (**Table 3**). To explore trends over time, we adjusted for clinical setting and imaging observation window. Univariate analysis for each of the eight remaining study factors are reported in **Appendix 4**.

Simple imaging

We included 36 studies in the adjusted simple imaging model (**Figure 3**, panel a). Carey et al. (2015)[35] and Tacci et al. (1999)[66] were extreme outliers, so were excluded from the model (shrunken residual=3.4 and 3.1, respectively). We found no significant change in the proportion of simple imaging over 20 years from 21.2% (95%CI 16.2 to 27.2) for imaging requested in 1995, to 21.3% (95%CI 16.4 to 27.2) for imaging requested in 2015. Similarly, clinical setting and imaging observation window were not associated with frequency of simple imaging in the adjusted model.

Complex imaging

We included 27 studies in the adjusted complex imaging model (**Figure 3**, panel b). Carey et al. (2015)[35] was an extreme outlier, so was excluded from the model (shrunken residual=7.4). We found an absolute predicted increase in imaging proportion (P=0.03) from 7.4% (95%CI 5.7 to 9.6) for imaging requested in 1995, to 11.4% (95%CI 9.6 to 13.5) for imaging requested in 2015, equivalent to a relative increase in complex imaging of 53.5%. Clinical setting was associated with frequency of complex imaging (P=0.001) with an imaging proportion of 17.8% (95%CI 13.5 to 23.0) for imaging requested in primary care, and 10.9% (95%CI 9.9 to 12.1) for imaging requested in emergency care. Length of observation window was also associated with frequency of complex imaging (P=0.001) with an imaging proportion of 8.4% (95%CI 7.3 to 9.6) for imaging requested within 4 weeks of the initial visit, and 11.7% (95%CI 10.2 to 13.3) when imaging was measured across the whole study observation window. These three factors accounted for most of the variance in frequency of complex imaging (adjusted R^2=75.3%).

Discussion

Statement of principal findings

There is moderate quality evidence from eight studies that during the 'current' phase approximately one quarter of patients who presented to primary care were referred for imaging, and high-quality evidence from four studies that approximately one third of patients who presented to emergency care were imaged. Based upon 27 studies (n=8,742,444) we found a 53% relative increase in complex imaging from 1995 to 2015. When all studies were considered, more complex imaging was requested in primary care compared to emergency care. We found no change in frequency of simple imaging over the same period.

Strengths and limitations of review

The strengths of this systematic review include use of a pre-specified protocol, inclusion of studies published in languages other than English and consideration of all studies published after the introduction of the first clinical imaging guideline.[18] We located studies from primary and emergency care as representative of settings where patients may seek care for LBP,[59] and provide summary data in a graphical format which enables clinicians to interpret unbiased imaging estimates, assessed for quality using the GRADE system.

One limitation was the magnitude of between study variance when estimating imaging proportion. To address this, we first grouped by setting and imaging type before applying random-effects meta-analysis. We applied mixed-effects meta-regression to further explain sources of heterogeneity with the number of factors in the adjusted model constrained to avoid overfitting. In addition, we adjusted for imaging observation window for trends in frequency of diagnostic imaging over time. Due to the greater percentage of North American studies (69%) we advise caution when interpreting data based on geographic region. Eleven studies (24%) counted imaging requests instead of imaging events alone. The calculated imaging proportion from these studies may be over-estimated given that not all imaging requests will be realised due to a range of issues (eg, patient choice, radiologist clinical consultation). Compared to imaging events, requests for simple imaging were higher (unadjusted model),

with no significant difference found between requests and events for complex imaging (**Appendix 4**). We were unable to extract sufficient data on some pre-specified study-level factors (eg, older age, duration of episode, presence of radicular syndrome) that may have influenced imaging rates. It remains unclear how these factors are associated with imaging proportions.

In relation to other studies

We believe this is the first systematic review of how commonly imaging was performed for patients who seek care for LBP. As such, we are unable to compare our results with previous reviews. Our study is a clear advance over non-systematic/narrative estimates from individual studies. For example, one study[74] used the proportion of elderly patients who underwent imaging for acute LBP[60] to estimate the potential cost saving across the adult US population in a campaign that targeted unnecessary imaging.

Imaging for LBP in the absence of indications of underlying pathology does not improve clinical outcomes,[75] but we found that radiography ordering did not diminish over 20 years. Further, we found complex imaging (which includes CT imaging) had increased over the same period. These findings align with a recent study by Morrisroe et al. (2018)[76] who reported a relative increase of 74% in Medicare-funded CT scans in Australia for LBP (195,000 in 2004 vs 340,000 in 2015), whilst billing for radiography remained static over the same period. Similarly, Deyo et al. (2009)[77] described a relative increase of 307% in Medicare Part B claims for lumbar spine MRI in the 12 years from 1994.

Meaning of the study: possible explanations and implications for clinicians and policymakers

We found that imaging for LBP remains high and has not decreased despite guideline advice, education campaigns and imaging referral decision systems. This pattern is consistent with a recent systematic review which found most interventions do not reduce imaging.[78] There is a

need for more research in this area to develop new strategies to reduce unnecessary imaging. This investment in research can be justified by the 'costs' of unnecessary imaging. Unnecessary imaging wastes scarce health resources and in the case of radiographs, CT and nuclear medicine, increases the risk of iatrogenic disease (cancers) because of cumulative ionising radiation.[79 80] Another cost is that the risk of overdiagnosis increases with imaging (especially with complex imaging).[12] This can promote poorer health outcomes through misguided patient or clinician concern,[81 82] medicalisation of pain,[83] or through unfounded confidence that incidental findings on imaging are the cause of LBP.[82 84 85] The implication is that high levels of non-indicated imaging may contribute to the disease burden of LBP,[1] iatrogenic disease, and perpetuate low value care.[86-88]

Unanswered questions and future research

The drivers of excessive imaging are multifactorial and incorporate many aspects of the health system including sluggish imaging guideline reform,[89] reliance on individual red flags that offer little or no diagnostic value when a patient is triaged toward further investigations including imaging,[90 91] regional variation (eg, different interpretations of legislation),[44] cultural practices (eg, patient/practitioner beliefs),[92] or financial interest (eg, clinicians with financial interest in MRI scanners).[93] The majority of studies in our review either did not explore drivers of excessive imaging, or focused on a single issue such as health insurer variation[36] or effect of clinical decision support.[33] The complete picture of what drives excessive imaging when patients present with LBP remains unanswered.

There is a paucity of research that has investigated effectiveness of interventions to reduce imaging for LBP. A systematic review by Jenkins et al. (2015)[78] found only in-hospital imaging decision support and targeted reminders reduced imaging referral, but recommendations were limited due to the low number of included studies, study heterogeneity and risk of bias. A recent study that investigated the effectiveness of decision support during imaging requests in

the ED found a reduction in the volume of imaging after implementation.[94] Involvement across multiple levels of healthcare (eg, clinicians, policy makers, payers, technology developers) has been recommended to help facilitate the adoption of clinical imaging decision support systems.[95] Artificial intelligence algorithms may also assist clinicians with appropriate decisions about imaging,[96] but have yet to be tested in the initial management of LBP. Similarly, natural language processing algorithms when applied to large volumes of imaging request/report data, may assist researchers to build improved clinical decision models for management of LBP.[97 98] Further research to evaluate strategies aimed at reducing imaging as a contributor to overdiagnosis must be prioritised.[12]

Conclusion

We report moderate quality evidence from 'current data' that about one quarter of patients who presented to primary care for low back pain were referred for imaging, and high-quality evidence that about one third of patients who presented to emergency care were imaged. Importantly, complex imaging has increased by 50% over 21 years despite guideline advice and education campaigns. These results draw attention to high levels of imaging in both primary and emergency care settings.

Summary box

What is already known

The vast majority of low back pain has no patho-anatomical cause; patients should not undergo routine diagnostic imaging.

Overuse of imaging for low back pain has been reported for decades.

What are the new findings

We have moderate quality evidence that about one quarter of patients who presented to primary care for low back pain were imaged. We have high-quality evidence that about one third of similar patients who presented to emergency care were imaged.

The rate of complex imaging per patient increased by 50% from 1995 to 2015.

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Ethical approval: Not required.

Declaration of transparency: The lead author (AD) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

List of Tables

Table1. Characteristics of included studies
Shaded cells = Combined imaging reported
Abbreviations: 'dash' = Not reportable; APAC = All-Payer All-Claims; B/S = Bone scan; BCBSM = Blue Cross Blue Shield of Michigan; BCBSTX = Blue Cross Blue Shield of Texas; BEACH = Bettering the Evaluation and Care of Health; Ch = Chiropractic; CT = computed tomography; D-RISC = Disability Risk Identification Study Cohort; ED = Emergency department/emergency care/emergency clinician; E = Imaging event; GP= General practice/general practitioner/primary care physician/family practice; MEPS = Medical Expenditure Panel Survey; MHS = Military Health System; mod = moderate MRI = magnetic resonance imaging; N. America = North America; NHAMCS = National Hospital Ambulatory Medical Care Survey; NAMCS = National Ambulatory Medical Care Survey; NZ ACC = New Zealand Accident Compensation Corporation; OHD = Outpatient hospital department; Ost = Osteopathy; PT = Physical therapy; R = Imaging request; UK = United Kingdom; UUHP= University of Utah Health Plans; U/S = Ultrasound; W/C = Workers' compensation; XR = X-ray (radiography).

Table 2. Risk of bias assessment
*Modification was made to two of the original 10 items:[19] The definition of the target population (item 1) was modified to include only patients seeking care for LBP. We did not downgrade for geographic location or single health insurer. The length of the shortest prevalence period (item 9) was modified to the delay between index visit and request/imaging event (low risk ≤4weeks).

Table 3. Pre-specified study-level factors
*Included in the adjusted model †Study-level factors present in <85% of studies were ineligible for meta-regression modelling.

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Figure 1. PRISMA flow

Figure 2. Current imaging proportion in primary and emergency care ordered by summary risk of bias (high to low)
Pooled imaging proportions were calculated using random-effects meta-analysis. The 'Any imaging' sub-group contains only studies that reported both simple and complex imaging types. Carey et al. (2015)[35] was considered an outlier so was not pooled. Pooled estimates were assessed for quality using GRADE criteria, downgraded for: *greater than 50% of studies were scored moderate or high risk for summary risk of bias (ROB); †point estimate range was greater than 25%.

Figure 3. Influence of study-level factors on imaging proportion
Panels (a) and (b) represent trends in frequency of simple and complex diagnostic imaging since the introduction of clinical imaging guidelines. All models were calculated in the logit space, adjusted for clinical setting and imaging observation window. Circles represent the imaging proportion for each study sized according to inverse of the within-study variance, but do not reflect the study weighting in the statistical model. Each fitted line was calculated using mixed effects meta-regression back transformed from the logit scale. *Adjusted mean proportion and their 95%CI estimates were statistically adjusted for the presence of factors in the mixed-effects model including year, clinical setting and imaging observation window held constant at their means. †Significant influence ($p < 0.05$) for each factor in the adjusted model.

Supplemental material (separate file)

Appendix 1. MEDLINE search string

Appendix 2. Imaging proportion for all studies grouped by care setting and image type listed by descending date order of mid-point in data collection

Appendix 3. Sensitivity analyses for current imaging proportions based on summary risk of bias

*No study scored high for summary risk of bias in the Emergency care setting †Total between group difference (mixed effects analysis)

Appendix 4. Association of study-level factors on imaging proportion for all studies (univariate analysis)

*Extreme outlier studies were excluded from each regression analysis based on a plot of standardised shrunken residuals ǂProportion of imaging for each factor in the univariate model).

Checklists (separate file)

- PRISMA checklist
- MOOSE checklist

Table1. Characteristics of included studies

Citation	Sampling frame	Study design	Data source	Geographic region	Clinical setting(s)	Clinical presentation	Study n	Imaging count (Request/Event) with imaging proportions per modality (%)					Age range	Mean age (SD)	% female	Summary risk of bias score
									XR	CT	MRI	U/S	B/S				
Allen, 2014[31]	2001-09	Retrospective time series	W/C database	N. America	GP, PT, Ch	LBP±radicular	10406	E:	35.3	2.7	11.5	0.6	-	-	49.4	23.8	mod
Ammendolia, 2007[32]	2004	Prospective cohort study	Medical records*	N. America	Ch	LBP	448	R:	12.3	-	-	-	-	>18	39.2 (13.6)	43.0	mod
Blackmore, 2011[33]	2003-05	Retrospective review	Health insurer	N. America	GP, ED	LBP	4605	E:	-	-	12.0	-	-	-	-	-	mod
Britt, 2014[34]	2002-05	Prospective cohort study	BEACH study	Oceania	GP	LBP	11146	R:	10.5	4.7	0.2	0.4	0.3	All	-	51.7	low
Britt, 2014[34]	2009-12	Prospective cohort study	BEACH study	Oceania	GP	LBP	10584	R:	9.1	6.1	0.8	0.6	0.2	All	-	55.3	low
Carey, 2015[35]	2010	Patient survey	Patient interview	Oceania	GP	LBP	211	E:	56.9	45.0	35.1	-	-	>18	-	61.0	high
Charlesworth, 2016[36]	2013	Retrospective review	Oregon APAC claims	N. America	GP	LBP	101530	E:		17.0			-	18-64	-	-	high
Childs, 2015[37]	2007-13	Retrospective review	MHS Reporting Tool	N. America	GP	LBP	753450	E:	-	-	11.7	-	-	18-60	36.9 (12.5)	46.8	mod
Crow, 2009[38]	2002-05	Retrospective review	Medical records	N. America	OHD	LBP	2030	E:	66.5	-	2.6	-	-	10-90	43.0	64.5	high
Dey, 2004[7]	1999	RCT (control arm)	Medical records	UK	GP	LBP	1138	R:	13.7	-	-	-	-	18-64	41.3 (12.5)	54.3	high
Feuerstein, 2004[39]	1997	Patient survey	MEPS 1997 survey	N. America	GP	LBP	1082	E:	21.0	-	-	-	-	18-64	-	-	mod
Friedman, 2010[40]	2002-06	Retrospective review	NHAMCS database	N. America	ED	LBP±radicular	4377	E:	30.5	-	-	-	-	≥14	40.0	51.2	low
Fritz, 2008[42]	2003-05	Retrospective review	IHC Rehab. Database	N. America	PT	LBP	471	E:	9.8	1.4	13.8	-	-	18-60	41.2 (11.0)	53.9	high
Fritz, 2013[41]	2004-08	Retrospective review	IHC Rehab. Database	N. America	PT	LBP	4368	E:	23.0	-	-	-	-	>18	39.9 (12.3)	50.1	mod
Fritz, 2016[43]	2012-13	Retrospective review	IHC Rehab. Database	N. America	GP, Ch, PT, Physiatry	LBP	747	E:	32.6	-	-	-	-	18-60	38.2 (10.7)	61.2	mod
Ganduglia, 2015[44]	2008	Retrospective review	BCBSTX database	N. America	OHD	LBP	645423	E:	-	-	14.5	-	-	18-64	-	-	high
Ganduglia, 2015[44]	2011	Retrospective review	BCBSTX database	N. America	OHD	LBP	749391	E:	-	-	14.6	-	-	18-64	-	-	high
Gonzalez-Urzelai, 2003[45]	1998-99	Prospective cohort study	Medical records	Europe	GP	LBP±radicular	105	E:	18	-	-	-	-	18-65	45.0 (12.9)	59.1	mod
Graves, 2012[46]	2002-04	Prospective cohort study	D-RISC W/C database	N. America	GP, ED, PT, Ch, Ost	LBP±radicular	1226	E:	-	-	18.6	-	-	>18	-	29.0	high
Graves, 2014[47]	2002-04	Prospective cohort study	D-RISC W/C database	N. America	GP, ED, PT, Ch, Ost	LBP±radicular	1770	E:	30.4	5.4	19.0	-	-	>18	-	32.0	high
Hong, 2017[14]	2010-14	Retrospective review	Optum Insight	N. America	GP, Ch	LBP	1547870	E:	21.5	6.8		-	-	18-64	-	54.8	low
Isaacs, 2004[48]	1998-00	Retrospective review	NHAMCS	N. America	ED	LBP	3074500	E:	17.8	4.3	0.7	-	-	18-70	-	58.7	mod
Jackson, 2005[49]	1995-97	Retrospective review	NAMCS	N. America	GP	LBP	10255661	E:	19.3	-	-	-	-	20-55	39.3	50.0	mod
Kerry, 2002[8]	1996-98	Prospective cohort study	Medical records	UK	GP	LBP	427	R:	22.3	-	-	-	-	18-64	41.1 (11.8)	54.1	high
Kost, 2015[50]	2011	Before and after study (before arm extracted)	Medical records	N. America	GP	LBP	123	R:	12	-	-	-	-	≥18	-	-	mod

Kovacs, 2006[51]	2003-04	Prospective cohort study	Medical records	Europe	GP	LBP	648	R:	15.6	2.2	2.5	-	-	≥18	46.5 (15.5)	52.2	low
Licciardone, 2008[52]	2003	Retrospective review	NAMCS	N. America	GP	LBP	253	E:	22.5		9.5			All	-	-	low
Lin, 2016[53]	2011	Before and after study	Medical records	Oceania	GP	LBP	77	R:		34		-	-	-	-	-	mod
Love, 2005[54]	1998	Retrospective review	NZ ACC (W/C)	Oceania	GP	LBP	129079	E:	12.1	-	-	-	-	-	-	-	high
May, 2016[55]	2013-14	Prospective cohort study	Clinical encounter	N. America	GP	LBP	55	R:	-	-	27	-	-	48	48 .0	0.0	mod
Michaleff, 2012[56]	2000-10	Prospective cohort study	BEACH study	Oceania	GP	LBP	5675	R:	19.2		4.2			All	-	-	low
Muntion-Alfaro, 2006[57]	2003	Retrospective review	Medical records	Europe	GP	LBP	538	R:	23.4	-	-	-	-	All	48.3	53.2	mod
Nelson, 2005[58]	1997-01	Retrospective review	Health insurer	N. America	GP, Ch	LBP	1709685	E:	31.8	9.0		-	-	All	34.0 (21.0)	52.0	mod
Nunn, 2017[59]	2009-15	Retrospective review	Medical records	N. America	ED	LBP	325	E:	27.4	5.2		-	-	≥16	43.0 (20.0)	55.1	low
Pham, 2009[60]	2000-06	Retrospective review	Medicare database	N. America	GP	LBP	35039	E:	24.0	3.9		-	-	≥65	-	69.3	high
Rao, 2015[61]	2013	Retrospective review	Medical records	N. America	ED, OHD	LBP	100	E:	7	5	12	-	-	5-96	48.0	50.0	low
Rizzardo, 2016[62]	2013	Retrospective review	Medical records	Europe	ED	LBP±radicular	1289	E:	41.0	2.6	1.4	-	-	All	63.5	49.0	mod
Rosenberg, 2015[63]	2010-13	Retrospective review	Medical records	N. America	GP, ED	LBP	206080	E:			53.4			19-50	-	-	mod
Salacka, 2009[64]	2006-08	Retrospective review	Medical records	Europe	GP	LBP	648	E:	19.3	-	-	-	-	19-60	-	58.3	high
Schlemmer, 2015[65]	2011-12	Retrospective review	BCBSM database	N. America	ED	LBP	14838	E:	26.3	4.4	3.5	-	-	18-64	-	52.8	low
Tacci, 1999[66]	1995	Retrospective review	W/C database	N. America	GP	LBP	98	E:	56	-	-	-	-	16-61	34.0 (11.0)	27.5	high
Tan, 2016[10]	2007-11	Retrospective review	Medicare database	N. America	GP	LBP	145320	E:	27.2	27.2		-	-	>65	-	-	mod
Thackeray, 2017[67]	2012-13	Retrospective review	UUHP database	N. America	GP	LBP	454	E:	16.5	4.6		-	-	17-60	40.4 (12.0)	70.7	mod
Walker, 2017[68]	2011	Retrospective review	Health insurer	Europe	GP	LBP	14358	E:	17.8	2.9		-	-	18-50	36.3	49.5	high
Weiner, 1999[69]	1995	Retrospective review	Medical records	N. America	ED	LBP	214	E:	18.7	-	-	-	-	≥16	-	-	low
Williams, 2010[9]	2001-04	Prospective cohort study	BEACH study	Oceania	GP	LBP	1830	R:	20.2	3.7	0.2	0.6	0.7	All	54.3	-	low
Williams, 2010[9]	2005-08	Prospective cohort study	BEACH study	Oceania	GP	LBP	1706	R:	19.6	6.2	0.1	1.1	0.1	All	56.0	-	low
Wilson, 2001[70]	1994-95	Survey	Patient interview	N. America	GP	LBP	522	E:	26	24	8	-	-	-	64 (14)	54.0	mod

Shaded cells = Combined imaging reported

Abbreviations: 'dash' = Not reportable; APAC = All-Payer All-Claims; B/S = Bone scan; BCBSM = Blue Cross Blue Shield of Michigan; BCBSTX = Blue Cross Blue Shield of Texas; BEACH = Bettering the Evaluation and Care of Health; Ch = Chiropractic; CT = computed tomography; D-RISC = Disability Risk Identification Study Cohort; ED = Emergency department/emergency care/emergency clinician; E = Imaging event; GP= General practice/general practitioner/primary care physician/family practice; MEPS = Medical Expenditure Panel Survey; MHS = Military Health System; mod = moderate MRI = magnetic resonance imaging; N. America = North America; NHAMCS = National Hospital Ambulatory Medical Care Survey; NAMCS = National Ambulatory Medical Care Survey; NZ ACC = New Zealand Accident Compensation Corporation; OHD = Outpatient hospital department; Ost = Osteopathy; PT = Physical therapy; R = Imaging request; UK = United Kingdom; UUHP= University of Utah Health Plans; U/S = Ultrasound; W/C = Workers' compensation; XR = X-ray (radiography).

Table 2. Risk of bias assessment

Study	1. Target population approximates typical national population seeking care for LBP*	2. Representative sampling frame	3. Random selection/census used	4. Minimal non-response bias	5. Appropriate mode of data collection	6. Acceptable case definition	7. Appropriate study instrument	8. Same mode of data collection for all	9. Appropriate delay between index visit and referral*	10. Appropriate numerator/denominator	Summary risk of bias
Allen, 2014[31]	-	+	+	+	+	+	+	+	+	+	Moderate
Ammendolia, 2007[32]	-	+	+	-	+	+	+	+	+	+	Moderate
Blackmore, 2011[33]	+	+	+	-	+	+	+	+	-	+	Moderate
Britt, 2014[34]	+	+	+	-	+	+	+	+	+	+	Low
Carey, 2015[35]	+	+	-	+	-	-	+	+	-	+	High
Charlesworth,	+	-	+	+	+	-	+	+	-	+	High
Childs, 2015[37]	+	-	+	+	+	+	+	+	-	+	Moderate
Crow, 2009[38]	+	-	+	+	+	+	+	+	-	+	High
Dey, 2004[7]	-	+	+	+	+	-	+	+	-	+	High
Feuerstein, 2004[39]	+	-	+	-	-	-	-	+	-	+	Moderate
Friedman, 2010[40]	+	+	+	+	+	+	+	+	+	+	Low
Fritz, 2008[42]	-	+	+	+	+	-	-	+	-	+	High
Fritz, 2013[41]	+	-	+	+	+	+	+	+	-	+	Moderate
Fritz, 2016[43]	-	-	+	+	+	+	+	+	-	+	Moderate
Ganduglia, 2015[44]	-	-	+	+	+	-	+	+	-	+	High
Gonzalez-Urzelai,	-	+	+	+	+	+	+	+	+	+	Moderate
Graves, 2012[46]	-	-	-	-	+	-	+	+	-	+	High
Graves, 2014[47]	-	+	-	-	+	-	+	+	-	+	High
Hong, 2017[14]	+	-	+	+	+	+	+	+	+	+	Low
Isaacs, 2004[48]	+	-	+	+	+	-	+	+	+	+	Moderate
Jackson, 2005[49]	+	-	+	+	+	+	+	+	-	+	Moderate
Kerry, 2002[8]	-	-	-	+	+	-	+	+	+	+	High
Kost, 2015[50]	+	-	+	+	+	+	+	+	-	+	Moderate
Kovacs, 2006[51]	+	-	+	-	+	-	+	+	+	+	Low
Licciardone, 2008[52]	+	+	+	+	+	+	+	+	+	-	Low
Lin, 2016[53]	-	-	+	+	+	+	+	+	-	+	Moderate
Love, 2005[54]	-	+	+	+	+	-	+	+	-	+	High
May, 2016[55]	-	-	+	+	+	-	+	+	+	+	Moderate
Michaleff, 2012[56]	+	+	+	-	+	-	+	+	+	+	Low
Muntion-Alfaro,	+	+	+	+	+	+	+	+	-	+	Moderate
Nelson, 2005[58]	-	-	+	+	+	+	+	-	-	+	Moderate
Nunn, 2017[59]	+	-	+	+	+	+	+	+	+	+	Low
Pham, 2009[60]	-	+	+	+	+	+	+	+	-	+	High
Rao, 2015[61]	+	+	+	+	+	-	+	+	+	+	Low
Rizzardo, 2016[62]	+	-	-	-	+	+	+	+	+	+	Moderate
Rosenberg, 2015[63]	+	+	+	+	+	+	+	+	-	+	Moderate
Salacka, 2009[64]	-	+	+	-	+	-	+	+	-	+	High
Schlemmer, 2015[65]	+	+	+	+	+	+	+	+	+	+	Low
Tacci, 1999[66]	-	-	+	+	+	+	+	+	+	+	High
Tan, 2016[10]	-	-	+	+	+	+	+	+	+	+	Moderate
Thackeray, 2017[67]	+	+	+	+	+	+	+	+	+	+	Moderate
Walker, 2017[68]	-	-	-	+	+	+	+	+	-	+	High
Weiner, 1999[69]	+	+	+	+	+	+	+	+	+	+	Low
Williams, 2010[9]	+	+	+	+	+	+	+	+	+	+	Low
Wilson, 2001[70]	-	+	+	+	-	-	-	+	+	+	Moderate

*Modification was made to two of the original 10 items:[19] The definition of the target population (item 1) was modified to include only patients seeking care for LBP. We did not downgrade for geographic location or single health insurer. The length of the shortest prevalence period (item 9) was modified to the delay between index visit and referral/imaging event (low risk ≤4weeks)

Table 3. Pre-specified study-level factors

Factor	Variable type	Categories	Data available (%)
Year*	continuous	(midpoint date of study sample frame)	100
Clinical setting*	categorical	primary care; emergency care	100
Study design	categorical	prospective; retrospective	100
Data source	categorical	clinical encounter; insurer data; patient survey	100
Imaging count method	categorical	imaging event; imaging request	100
Geographic region	categorical	North America; Europe; Oceania; United Kingdom	100
Imaging observation window*	categorical	Imaging with 4w; imaging within study period	100
Imaging at first consultation	categorical	first; subsequent; any consultation	96
Workers' compensation†	categorical	yes; no	64
Duration of episode†	categorical	<3 months; ≥3 months	40
Older age (>64y)†	categorical	yes; no	38
Radicular syndrome†	categorical	yes; no	36

*Included in the adjusted model †Study-level factors present in <85% of studies were ineligible for meta-regression modelling.

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